Logistics of Aging Weapon Systems

Kim Triplett
Synergy, Inc

Outline

- What is “aging”
- Nature of Problem
  - Demographics
  - Systems Implications of Aging
  - Engineering Implications of Aging
  - Logistics Implications of Aging
- Possible Solutions
  - Engines/Powertrains
  - Electronics
  - Structural

What is “aging”?

- Aging includes:
  - System deterioration due to:
    - Time - corrosion (calendar age)
    - Use - stress (realized life)
  - Technological obsolescence
    - Reduced supportability (economic service life)
    - Degraded mission performance

Calendar Age

- Measured in terms of years in service
- Remaining life = design life - calendar years
- Replacement time = total inventory/yearly procurement
- Management metrics
  - Replacement time ≤ Service life
  - Compare actual age to half-life*
    - If actual > half-life ⇒ replacement time longer than service life and average age of system will increase

*Midpoint of System’s average service life in calendar years

Service Life

- Hours of use *and* how used
- Design life = hours of operation a system is designed to achieve
- Normal use = design life/service life
- System can "prematurely age" because of
  - Greater use than "normal"
  - More "stressful" use

Demographics

- Average Calendar Age:

Weapon System	Half-Life	1990	2000	2010	2020
USAF KC-135	25-33	29	39	49	59
USAF Fighters	10-15	6.0	13.5	20.1	13.3
US Army M1A	15	N/A	13	23	33
Navy Fighters	10-15	11	13	17	25

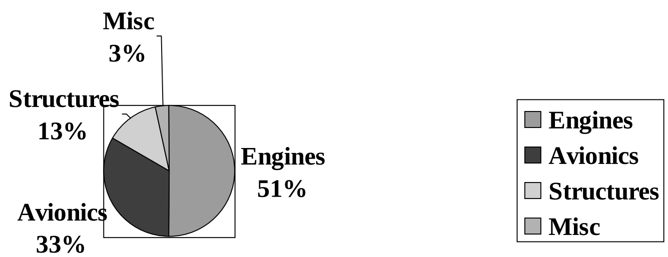
NOTE: RED indicate system exceeds half-life

System Implications of Aging

- Engine/Powertrain
  - Wear out
  - Environmental issues – noise, pollution
  - Safety issues – weight restrictions; catastrophic failures
- Electronic subsystems
  - Hardware/software obsolescence
  - Changing mission requirements/threats
- Structural
  - Corrosion fatigue
  - Fatigue
  - Stress Corrosion Cracking (SCC)

System Level AF Support Costs

Depot-Level Maintenance Costs

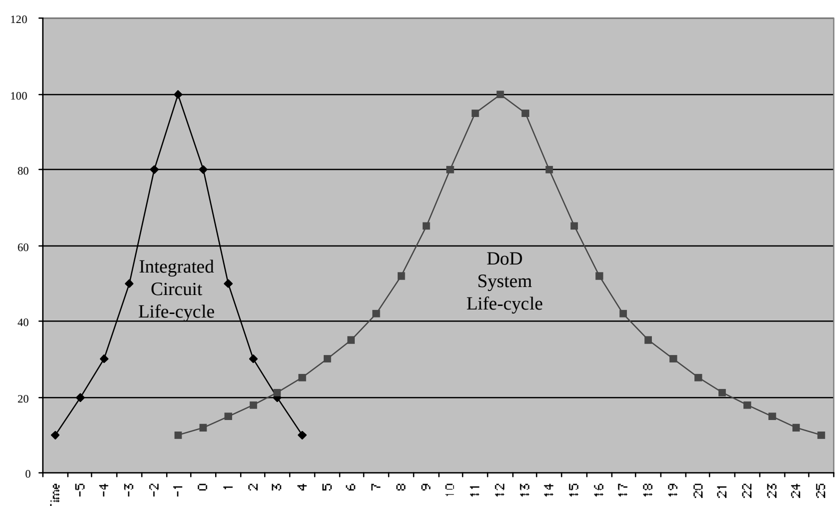


•Avionics costs expected to increase 50% in next 5 years

Engineering Implications of Aging

- Corrosion
  - Calendar age
  - Corrosive environments
- Fatigue Cracking
  - Stressful use - wearing out sooner than expected
  - Low and high cycle fatigue
  - Widespread fatigue damage (WFD)
- Stress corrosion cracking
  - 7XXX series aluminum alloys
- Technological Obsolescence
  - Diminishing sources of supply/out-of-production (DMS/OP)

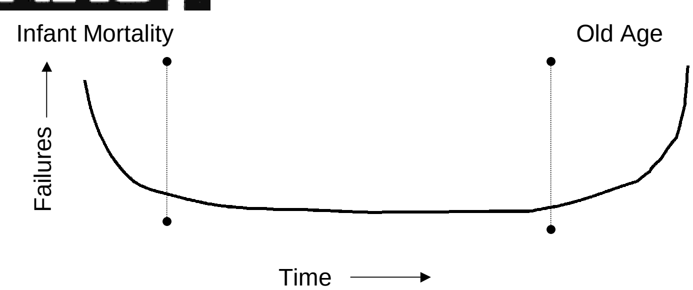
Life-Cycle Mismatch



Logistics Implications of Aging

- Decreased reliability
  - Bath tub curve
- Increased time in and costs for depot maintenance
- Decreased mission capable rates
- Increased maintenance hours per operating hour
- Parts shortages and increased cannibalization rates
- Decreased weapon system availability

Decreased system reliability

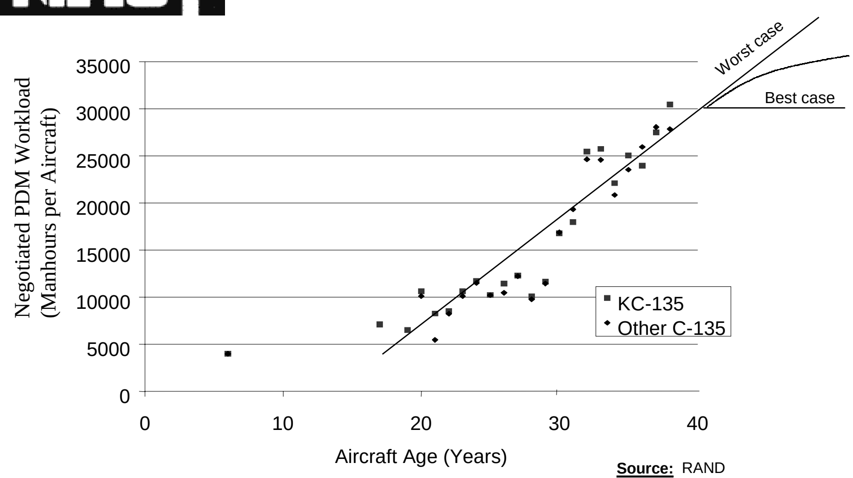


•Aging pushes systems to right-hand side of “bath tub” curve
  •Exponential increase in failure rates
•Aging systems can also experience failure of “lifetime” components
  •Components that were designed not to fail that fail because we keep systems past their design life
  •No maintenance/technical data on these components

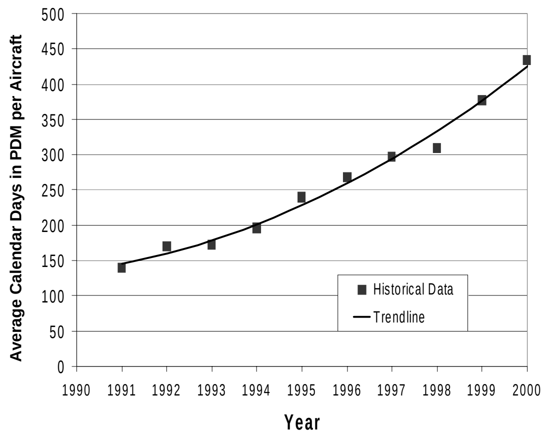
Increased depot maintenance time and costs

- Weapons system take more hours to fix in depot
- Weapon systems stay longer in depot
- More parts are replaced
- More weapons are found in depot than originally planned
- Consequently fewer systems operational and depot repair costs increase

KC-135 Growth in PDM Workload



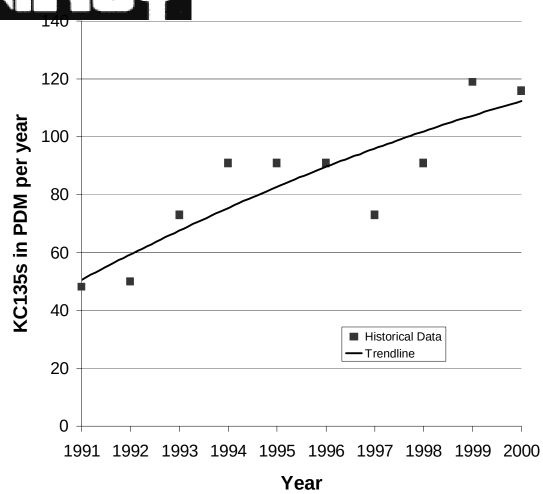
KC-135 Growth in PDM Duration



Source: OC-ALC

- Time in PDM increasing (excludes 30-32 days for aircraft modifications)
  - Due to corrosion and stress related cracking

KC-135 Growth in Aircraft at PDM



Source: OC-ALC

- Number in PDM increasing (excludes 40-50 for aircraft modifications)
  - Due to corrosion and stress related cracking

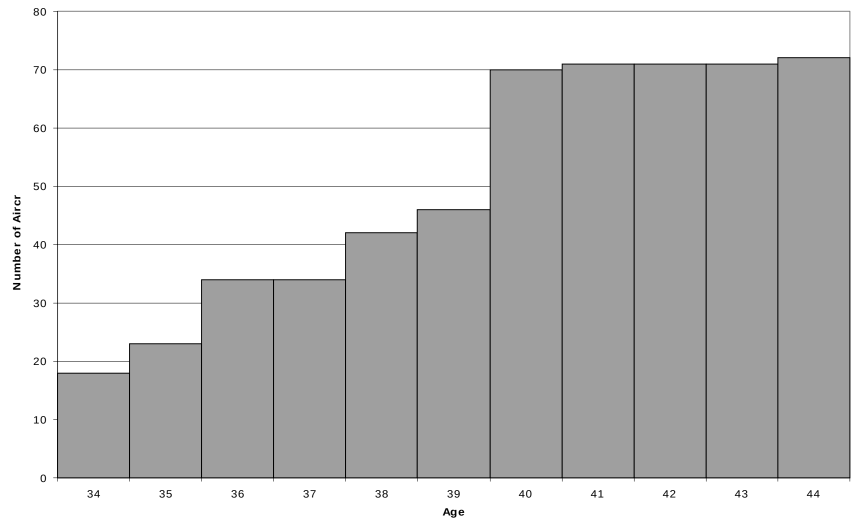
Problem Statement

- Aging KC-135 fleet poses risk to meet tanker warfighting requirements in the near or mid-term (2001-2020)
- Determine what is the best tanker investment plan for the near or mid-term

Study Approach/Assumptions

- Developed an ARENA simulation model to predict KC-135s available for operations based on the increasing PDM service times
- Collected Historical data from AMREP, G079 and REMIS including the age of the aircraft, owning organization, MDS, and utilization rate
- Produced output results from the ARENA simulation model in text files and read results into a Microsoft Access Database for analysis
- Determined PDM delay time using: historical distribution, linear, exponential, no growth, linear to 219 days, and logistics regression functions
- Used time between PDM actions approximately equal to five years
- Modeled unlimited capacity at PDM line (limited capacity can also be modeled)

Age of KC135 Fleet



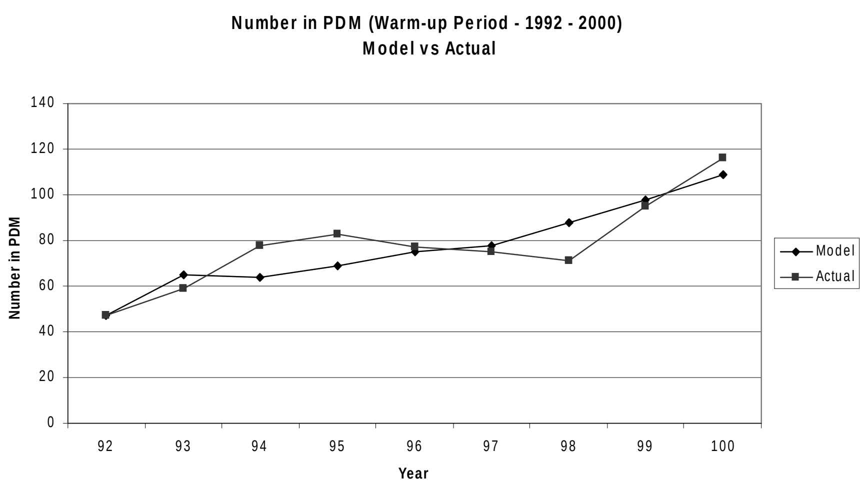
Functions Used for PDM Delay

Expression Name	Condition	Equation
Historical Distributions (called PDM Delay)	Based on Age Intervals	
	<=30	Exponential = (97+EXPO(49.9))
	31-35	Lognormal = (98+LOGN(136,176))
	36-40	Gamma = (62+GAMM(115,226))
	>40	Normal (Growth Factor applied to Mean) = NORM(366, 125)
Linear	Based on Current Age	14.991*Current Age – 269.06
Exponential	Based on Current Age	$26.814 * e^{0.0627 * \text{Current Age}}$
No Growth	Based on Current Age	$1/(1/390 + (1.9324 * 0.8054^{\text{Current Age}})$
Linear to 219	Based on Year	
	Warm-Up Period	30.694*YearWU + 91.18 (YearWU = Year + Warm Up Period)
	1 to 2 Yrs (= 2000 to 2001	-182.71*Year + 584.42
	Greater than 2 Years	219
Logistics Function	Based on Current Age	$1/(1/866 + (0.0617 * 0.9163^{\text{Current Age}})$

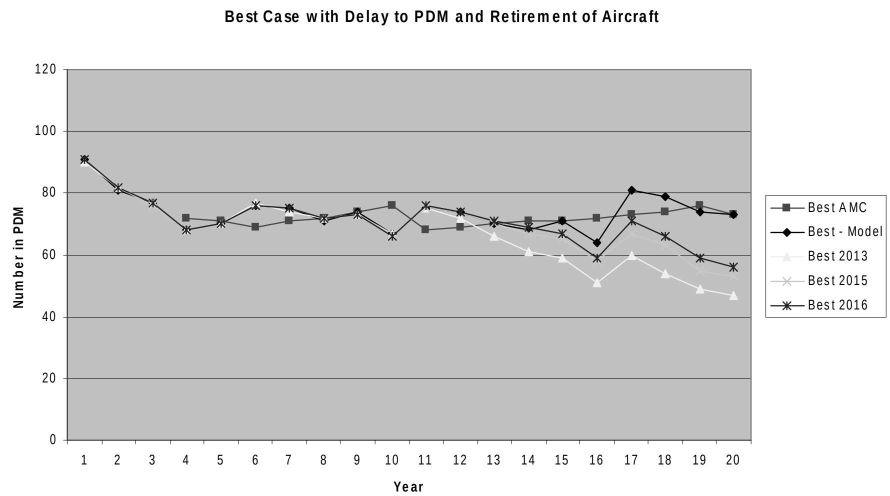
Analysis

- Compared availability of KC-135s vs. requirements for near or mid-term
- Predicted aircraft in PDM using all aircraft in service until 2020
- Predicted aircraft in PDM by buying 5 aircraft in 2013, buying 18 aircraft for each year thereafter until 2030
  - Oldest aircraft will retire starting with 5 in 2014 and 18 for each year thereafter
- Predicted aircraft in PDM by using a similar buy program starting in years 2014 and 2015

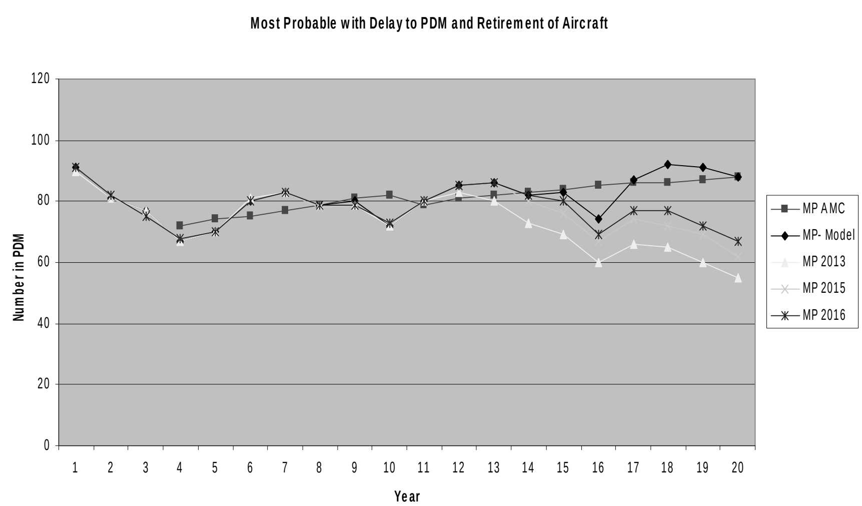
Results
Number in PDM



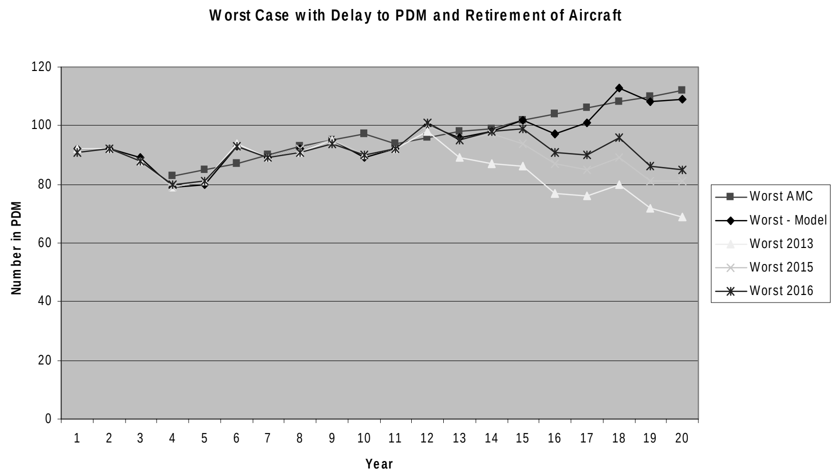
Results
Number in PDM



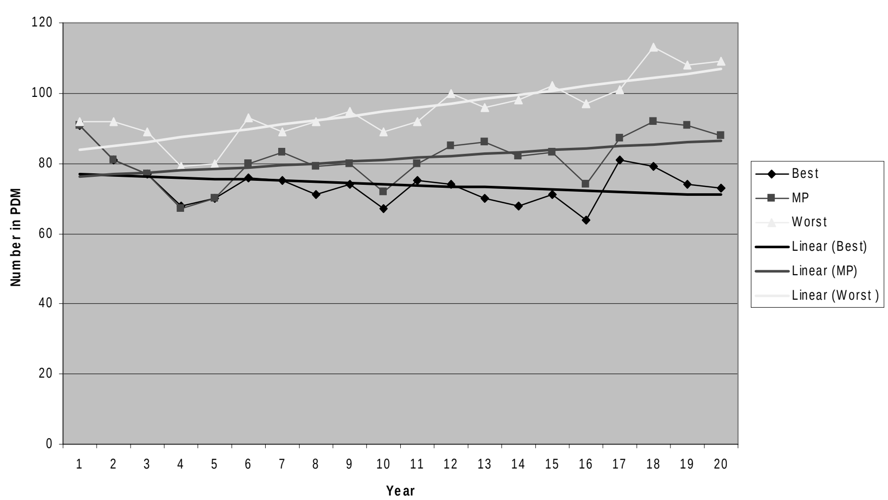
Results
Number in PDM



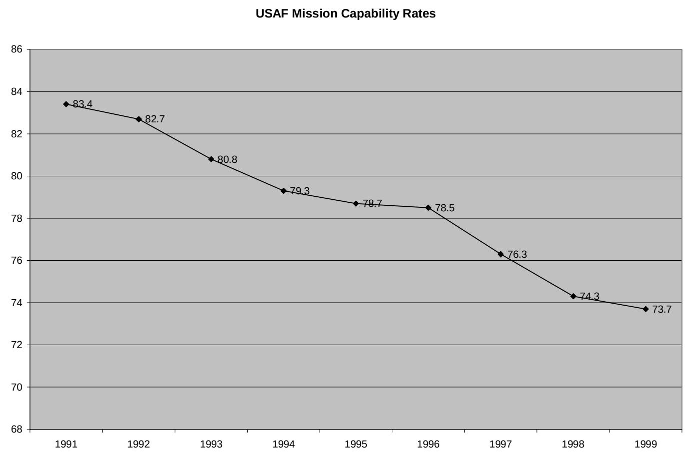
Results
Number in PDM



Results
Number in PDM

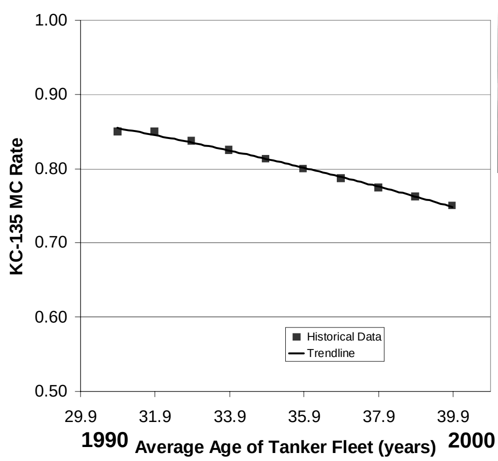


Decreased Mission Capability Rates



•Decline in Mission Capability rates in 1990's from around 83% to 73% for all USAF aircraft systems combined

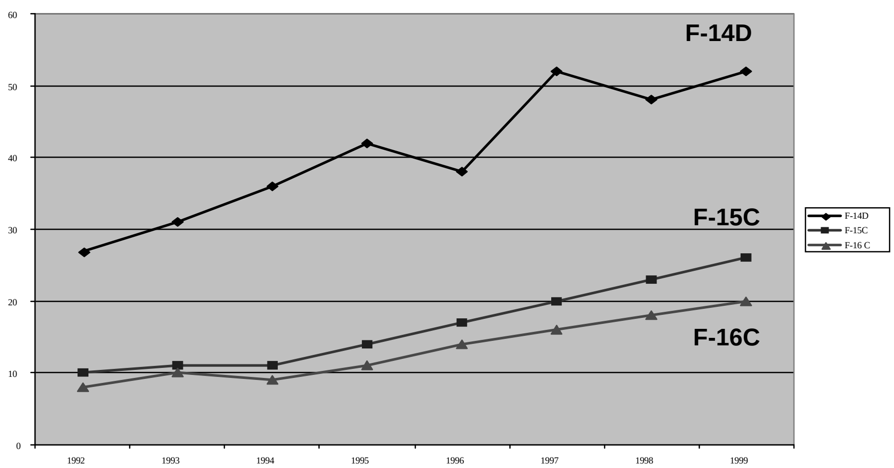
KC-135 Decline in MC Rate



Source:
MERLIN
Database

• Less KC-135s available due to declining MC Rates

Increased maintenance hours per flying hour



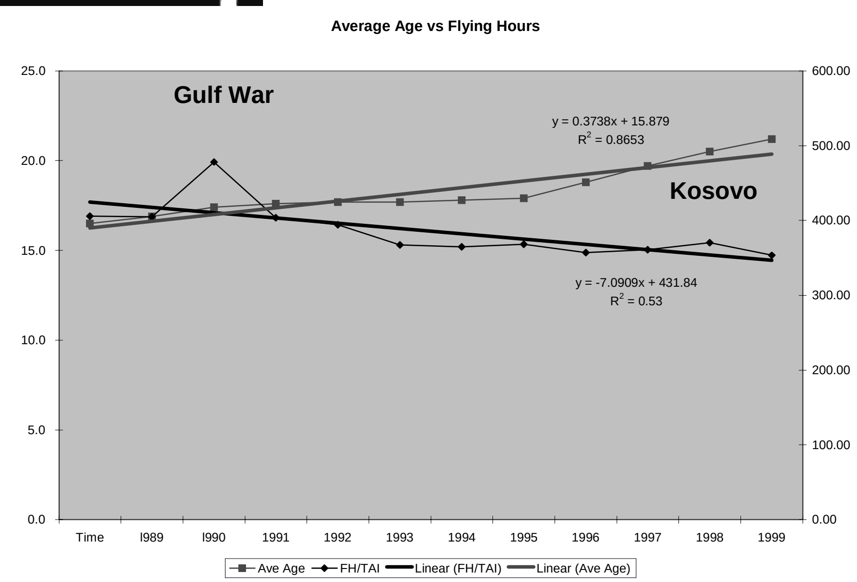
Increased use of cannibalization

- Lack of parts leads to:
  - AF aircraft cannibalization rates increased 78% from 1995 to 1998
  - Cannibalizing “doubles” maintenance time – have to remove and replace two parts to fix one part
  - Increased likelihood of breaking another part during its removal

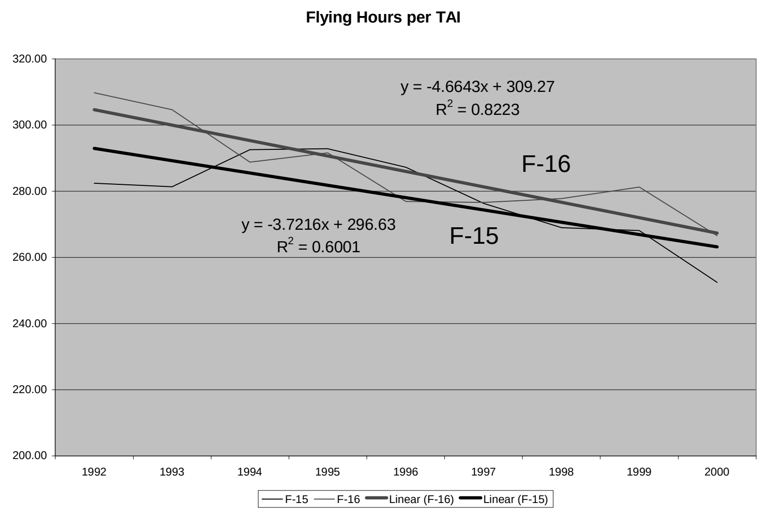
Decreased Availability

- More weapon systems in depot and for longer periods of time – decreases number of weapons systems that are at operational units
- Lower mission capable rates – increases the number of weapon systems deployed to ensure mission completion

Reduced Flying Hours



Reduced Fighter Flying Hours



Possible Solutions

- Engines/Powertrains
  - Replace
  - Rebuild
- Electronics
  - Diminishing Manufacturing Sources/Out of Production Solutions (DMS/OP)
  - Modular-Open-System-Architecture (MOSA)
- Structural
  - Service life extension Programs (SLEP)
  - Structural Integrity Programs
  - Corrosion prevention and control
  - Nondestructive evaluation
  - Prognostics
  - Economic service life estimates

QUESTIONS?

References

- Pierrot, Lane, Senior Analyst, National Security Division Congressional Budget Office; "CBO Testimony Statement on Aging Military Equipment before the Subcommittee on Military Procurement, Committee on Armed Services and U.S. House of Representatives"; 24 February 1999; available online at http://www.cbo.gov
- Pyles, Raymond; RAND Testimony; "Aging Aircraft: Implications for Programmed Depot Maintenance and Engine-Support Costs"; February 1999
- United States General Accounting Office, Report to the Secretary of Defense; "Tactical Aircraft: Modernization Plans Will Not Reduce Average Age of Aircraft"; February 2001; GAO-01-163
- United States General Accounting Office; "U.S. Combat Air Power: Aging Refueling Aircraft are Costly to Maintain and Operate; May 1996; GAO/NSIAD-96-160
- RAND; "Aging Aircraft: A Crisis on the Horizon (Parts I – III)"; available online at http://www.rand.org/paf/highlights/aging.html
- Congressional Budget Office; "The Effects of Aging on the Costs of Operating and Maintaining Military Equipment"; August 2001
- Committee on Aging of U.S. Air Force Aircraft, National Materials Advisory Board, Commission on Engineering and Technical Systems, and National Research Council; "Aging of U.S. Air Force Aircraft: Final Report"; National Academy Press; Washington D.C.; 1997; Publication NMAB-488-2; available online at http://stills.nap.edu/html/aging
- Committee on Aging Avionics in Military Aircraft, Air Force Science and Technology Board, Division on Engineering and Physical Sciences, and National Research Council; "Aging Avionics in Military Aircraft"; National Academy Press; Washington D.C.; 2001

SYNERGY

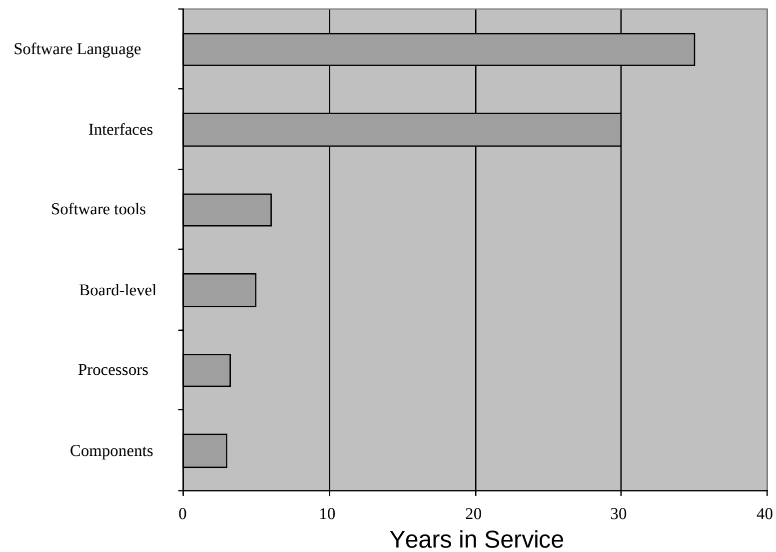
Back Up Slides

SYNERGY

Technological Obsolesce

- Commercial Off The Shelf (COTS)
  - Technology refresh cycle of 18 months
  - Availability cycle of 10 years
  - Military service lives exceed 15 years
- Military constitutes >1% of commercial market
- Diminishing manufacturing sources of supply/out-of-production (DMS/OP)
  - 1986 7.5% of all electronic devices discontinued
  - 1996 13.5% of all electronic devices discontinued

Time to Obsolescence



Software Obsolescence

- Increased costs of maintaining software maintenance tools
- Decreased number of personnel familiar with legacy software

Engine Solutions

SYNERGY

- Rebuild
  - Current rule of thumb - rebuild 2 cycles before replace
  - Looking at feasibility of doing more rebuilds before replacing
- Replace
  - Increased power/performance
  - Greater ability to meet noise restrictions

Electronics -DMS/OP Solutions

SYNERGY

- Diminishing Manufacturing Sources/Out of Production Solutions (DMS/OP)
- Purchase lifetime supply - increase inventory costs
- Redesign circuits to accept newer parts - increase system design costs
- Replace entire module or subsystems with new technology-acquisition costs and form, fit function problems

Electronics - MOSA Solution

- Modular-Open-System Approach
  - Scalable, more easily upgradeable avionics systems
  - Comprehensive MOSA Solution saves money in long run, but more costly than customized point solutions in the short run
- *Modular* systems involve isolation of functional performance from the specific characteristics of the software and hardware
- *Open* systems are usually modular but make use of nonproprietary interface definitions and standards available to multiple competitors

Service Life Extension Programs

- Structural Modifications:
- Navy to extend F-18C/Ds flying hours from 6,000 to 12,000
  - Cost of $2.5M per aircraft
- AF F-16's actual FH of 5,000 versus 8,000 planned due to stressful Ops
  - Mods to extend to 8,000 FHs
  - Cost of 400K per aircraft

Structural Integrity Programs

- Reduces likelihood of structural failure during design life through use of damage tolerance requirements
- Key is full scale durability testing to validate design service life based on operator’s planned mission profiles
- Difficulty is that few systems are used as originally intended

Corrosion Prevention & Control

- Prevention – deteriorates overtime
  - Proper selection of materials during design
  - Reduced humidity storage (30-40% relative humidity)
- Detection – early is better than later
  - Corrosion classification scheme
  - Increased time between depot repairs mitigates against early detection
- Repair
  - Very expensive in terms of both time and money
  - No loss of aircraft due to corrosion

Nondestructive Testing

- Technology to diagnosis and characterize structural damage to develop effective repairs
- Detection of fatigue cracks under fasteners
- Detection of small cracks associated with WFD
- Detection and quantification of hidden corrosion
- Detection of cracks in multilayer sections
- Detection of SCC in thick sections

Structural - Prognostics

- Predict failures before they occur
  - Trend lines
  - Leading Indicators
  - Uncover causal linkages
- Ongoing work in this area

Economic Service Life

- Determining and predicting when weapon system reaches point where it is appropriate to replace rather than repair
  - No clear methodology to accomplish
  - No clear definition of elements that constitute structural economic life
  - No clear methodology to forecast future costs
  - No standard economic/cost model to perform calculations
- Vehicle rule of thumb – retire vehicle once $XXXX in repairs performed